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THE 10 YEAR USSR KOSMOS SATELLITE PROGRAM

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Rudolf Hofstätter

ABSTRACT. Describes the Soviet Kosmos satellite and rocket program. These satellites have investigated solar radiation, astronomical data, astrophysical data, the Earth's atmosphere, space biology and other areas of research.

The great program for research of the cosmic space near the Earth and the upper layers of the Earth's atmosphere using artificial satellites of the Kosmos series was reported ten years ago, on 16 March 1962, by the Soviet news agency TASS. The important scientific missions of this program covered an extraordinarily wide range: /37*

- study of the density of charged particles in the Earth's ionosphere for study of radio wave propagation;
- investigation of the corpuscular radiation streams from the Sun, and particles with low charge;
- study of the energetic composition of the Earth's radiation belt to determine radiation danger in extended, and particularly in manned, space flights;
- determination of the original composition of cosmic radiation and its intensity variations;
- study of the Earth's magnetic field;
- study of the short wave radiation from the Sun and from other heavenly bodies;
- investigation of the upper layers of the Earth's atmosphere;
- study of the abundance of meteorites as well as the action of meteoritic materials on the construction and components of space apparatus;
- study of the spread, origin, and forms of the cloud cover of the Earth, and other meteorological missions;
- practical testing of new construction elements of artificial

*Numbers in the margin indicate pagination in the original foreign text.

satellites, unmanned testflights of spacecraft, etc.

THE KOSMOS BOOSTER ROCKET

The experiments by means of satellites of the Kosmos series have expanded unalterably from year to year. Thus, for example, 12 of these satellites were placed in Earth orbit in each of the years 1962 and 1963. By 1964, in comparison, there were 24 launches with 27 satellites (multiple launches), and in 1965 there were 36 launches. In 1966, 34 Kosmos satellites were placed in orbit, and there were 31 up to July, 1967. In the period 1966 to 1970, the number of launches tripled by comparison with the period 1962 to 1965 (286 artificial satellites of the Kosmos types as compared to 103). In 1971, one could point to 81 successful attempts. All in all, the Soviet scientists and technicians have helped in clarification of the following questions: How does a manned spacecraft, for example, behave on reentry into the Earth's atmosphere, and to what conditions is it exposed? How does the cosmic "milieu" affect the satellites and their design and construction elements? How can the occupants of manned space ships most effectively be protected from the dangerous action of cosmic radiation? and many more. Corresponding to the comprehensive and complex set of missions, the satellites of the Kosmos type have flown on several routes in space. Most of them were launched at an orbital inclination angle of 49, 51, 56, 65, or 69 degrees from the Earth's equatorial plane. The orbital inclination angle of 49 degrees is generally used for scientific satellites which do not require high accuracy in the orbital elements. If an exact orbital path is necessary, an orbital inclination of 65 degrees from the equator is used, as was the case, for example, with the satellites Kosmos 44, 58, 100, 103 and 122, as well as Kosmos 41, which was a test satellite for the 12-hour orbital path of the Soviet Molniya communications satellite. Within these standard routes, the orbital paths of the Kosmos satellites covered a very wide range of heights. While the maximum height of the first Sputnik did not exceed 1,600 km above the surface of the earth, and others have orbited only at the relatively low altitude of 150 km above the earth, others have penetrated space to as far as 60,000 km.

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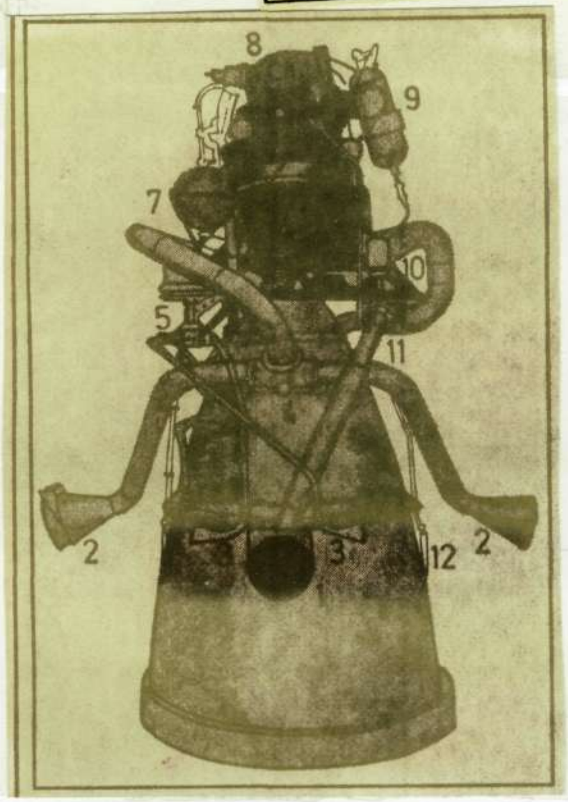
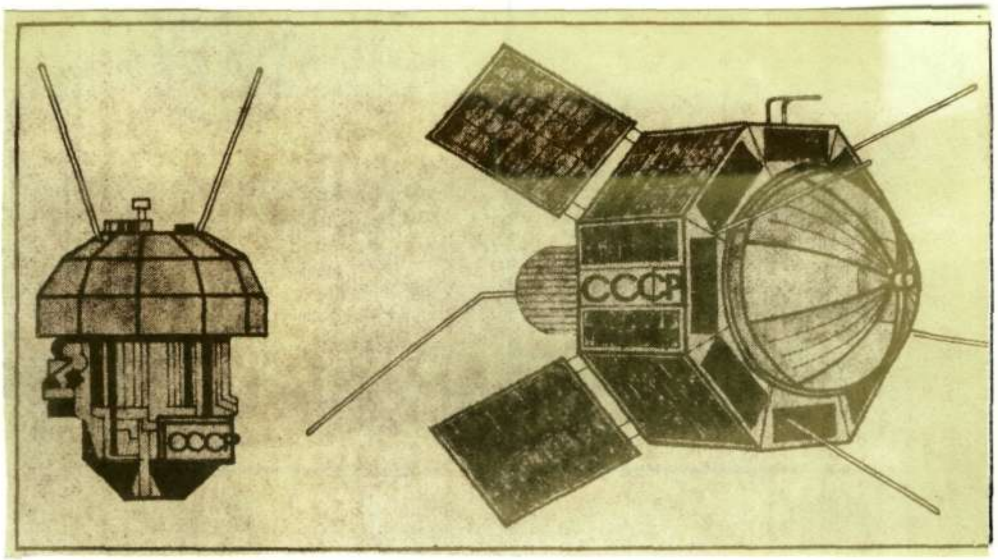
The missions of the Kosmos satellites are not limited to those concerning cosmic space directly. Instead, in the framework of the Kosmos program the Soviet scientists and technicians have also made a quite important contribution to the development of new booster rockets. Thus, for example, several booster vehicles (two, three, and four stage rockets) of different types and different load capacity were developed, because the weight of the Kosmos satellites varies depending on their scientific missions. This ranges from a few hundred kilograms for simple measuring satellites up to several tons for unmanned satellites of the size of manned spacecraft (Voskhod, Soyuz). The two stage booster rocket of the same name, Kosmos, which was first used in the launch of Kosmos 1 on 16 March 1962 is still used successfully even today. It is 30 m long and has a diameter of 1.65 m. The first stage of this booster vehicle contains the PD-214 engine with a thrust of 74 tons in empty space. It is the first powerful Soviet mass-production engine for high-boiling nitric acid oxidizer and petroleum processing products as fuel. This engine develops the highest thrust and specific thrust of the known engines in this class using nitric acid oxidizer and hydrocarbon fuel. The PD-214 engine is a four-chamber design with a common set of turbine pumps including the turbines, the centrifugal pumps for oxidizer and fuel (one each) as well as the pump for hydrogen peroxide to supply the gas generator. The products of catalytic decomposition of hydrogen peroxide in the gas generator serve to start the turbine. The superheated steam which operates the turbine is removed through a nozzle which generates additional thrust. The chambers are cooled regeneratively (with fuel) as well as with the internal fog produced by the combustion chamber injection jets. The inside diameter of the combustion chamber is 480 mm, and the diameter of the critical nozzle orifice 176 mm. Chemical ignition occurs with the starting fuel which ignites spontaneously on contact with the main oxidizer. The starting fuel is stored in the main line ahead of the fuel pump. The engine is started without an intermediate thrust stage. Thrust is controlled in flight by changing the consumption of hydrogen in the gas generator. The engine is turned off beyond the final stage. Thrust vector control is by means of the gas jet rudder. The PD-214 engine has been used with the prototype of the Kosmos rocket since 1957 and is one of the earlier developments.

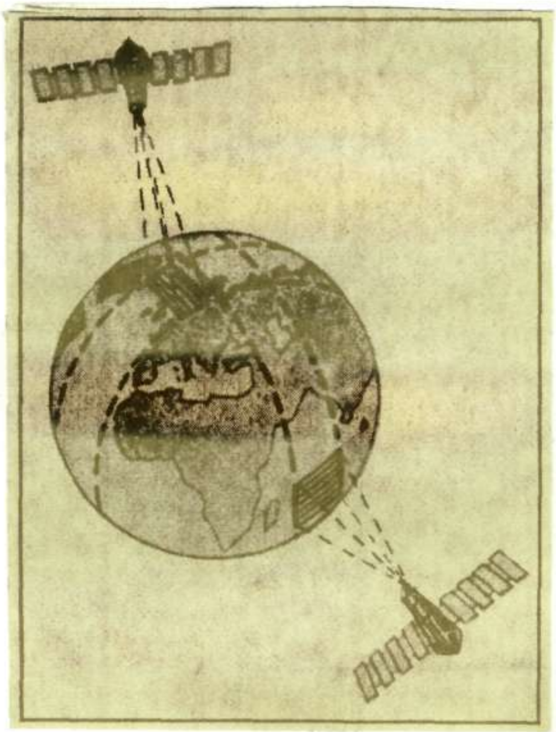


Oxygen-dimethylhydrazine engine, PD-119, for the second stage of the Kosmos carrier rocket: 1 = control nozzles for the system (the second nozzle is on the opposite side), 2 = course control nozzles (yaw nozzles), 3 = pitch control nozzles (second pair on opposite side), 4, 5, and 11 = gas distributor with electrical drive, 6 = combustion chamber, 7 = spherical flask for compressed air, 8 = turbine pump assembly, 9 = gas generator, 10 = mounting frame, 12 = removable locking cap. Engine data: thrust /38 in empty space: 11 tons; specific thrust in empty space: 352 seconds; pressure in the combustion chamber: 80 atmospheres; expansion ratio of the gases: 1,350; fuel components: oxidizer — liquid oxygen, fuel — unsymmetrical dimethylhydrazine.

The second stage of the Kosmos carrier rocket has the PD-119 engine with a thrust of 11 tons. It is designed for use of oxygen and unsymmetrical dimethylhydrazine as fuel. This fuel was developed in the period 1958 - 1962. It has the highest thrust in empty space (for oxygen engines using high-boiling fuel): 352 seconds. The PD-119 engine consists of a combustion chamber with an injection jet head and a profiled nozzle; a set of turbine pumps with centrifugal pumps for fuel and oxidizer (one each); single component gas generator for the main fuel, which is decomposed thermally; a complex of automation systems, including the thrust controller and the controller for the ratio of fuel components; control nozzle system with gas distributors; mounting frames on which the auxiliary equipment is installed; the frames also serve to connect the engine



Design examples of Kosmos series satellites: an Earth satellite with solar cells and solar cell paddles.

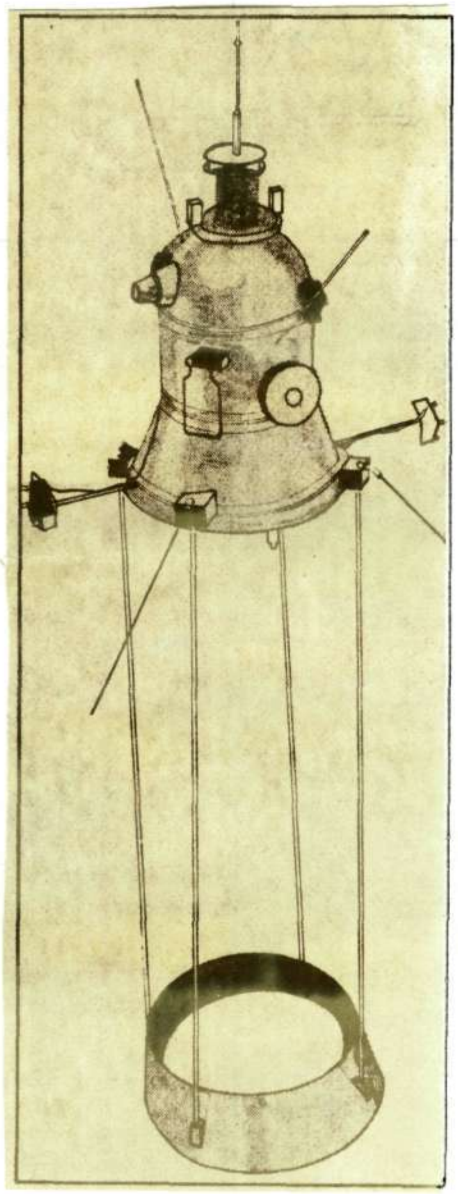


Position of the satellites in the meteorological system.

to the rocket. Titanium and other modern construction materials are used extensively in the engine construction. The inside diameter of the combustion chamber is 210 mm and the diameter of the critical nozzle orifice is 93 mm. The engine control system is designed for control and orientation of the second stage of the Kosmos rocket in flight. Control is by means of redistribution of the turbine exhaust gases between fixed control nozzles. The engine is started and controlled automatically by the command center on the rocket. Ignition is provided by a pyrotechnic system which ensures reliable (automatically controllable) functioning under flight conditions. The turbines and pumps are originally run up by means of a pyrotechnic charge in the gas generator. In flight, thrust is controlled through change in fuel consumption due to loading the gas generator. (These statements on the two stages and the PD-214 and PD-119 engines of the Kosmos carrier rocket were taken from the brochure "GDL-OKB / 1929 until 1969" by Prof. G. W. Petrowitsch.)

Sputniks Discover Space

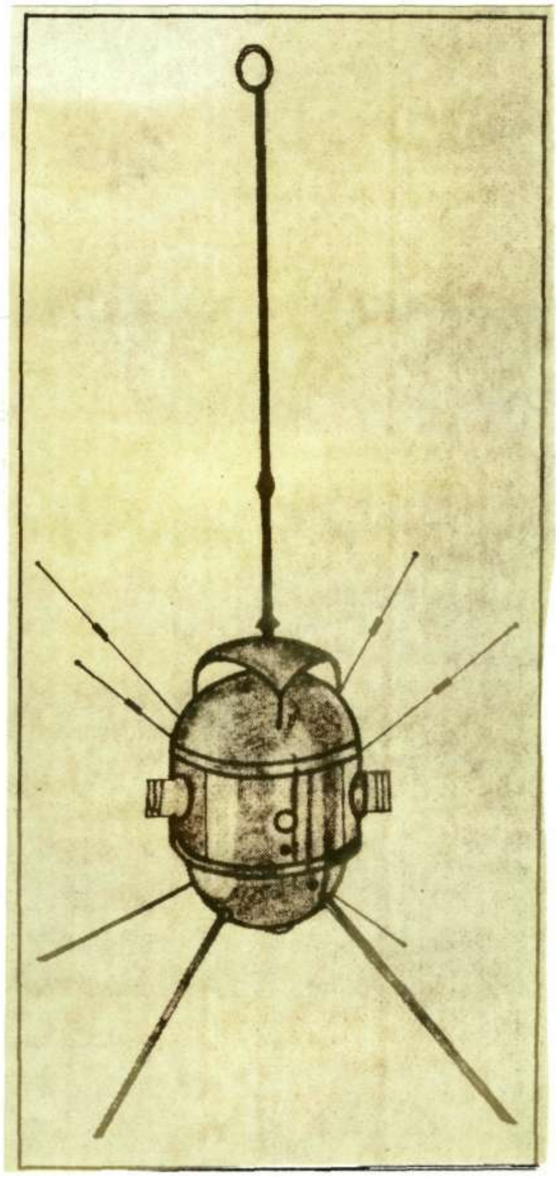
Aside from the two-stage Kosmos carrier rocket, the Soviet scientists and engineers have also produced launch vehicles by means of which several satellites can be launched at once. Depending on the scientific requirement, there can be two, three, five, or even eight. These Sputniks are all identically instrumented, so that in this way, simultaneous measurements can be undertaken in different regions of cosmic space. This was the case, for example, in the experiment with the satellites Kosmos 38 to 40 and Kosmos 80 to 84. On one of the latter satellites, furthermore, the power supply system was one which derived its energy from radiation from radioactive isotopes. This generator worked on the principle of thermoelectric conversion of radioactive energy. Of course, precautions were taken to prevent spread of radiation in the atmosphere or on the surface of the earth. Such an experiment was then repeated with the multiple-launch Kosmos 86 to Kosmos 90. Three times, eight satellites were launched at once, in April 1970 (Kosmos 336 to 343), in May 1971 (Kosmos 411 to 418), and in October 1971 with Kosmos 443 to 451. In all, there have been nine multiple launches since the beginning of the program in 1962 by the Soviets. Kosmos 434, too, was the



An "optical" Earth satellite of the Kosmos 149 type with an aerodynamic stabilization system. The extensible boom, which is thin and several meters long, carries a massive cone-shaped ring, the stabilizer.

five-hundredth space satellite launched into Earth orbit since the launch of Sputnik 1 in October 1957. This does not count the lunar, planetary, and other probes. The Kosmos satellites were launched not only from the well-known Kosmodrome of Baikonur (Kasazhstan) but also from other launching sites on USSR territory.

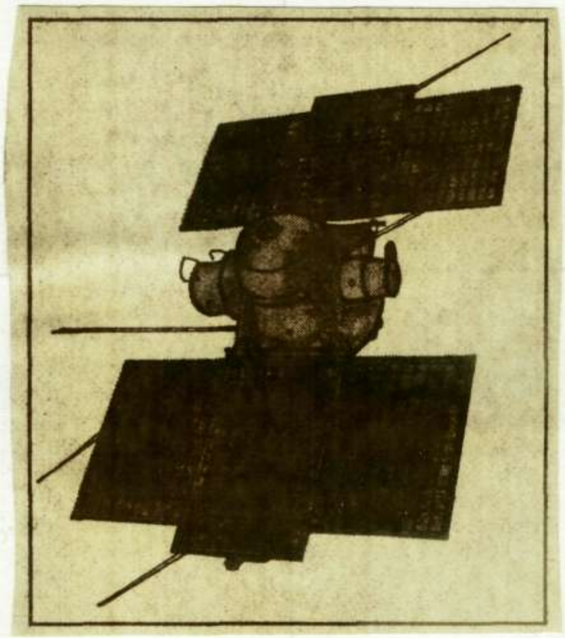
The 500 sputniks which have been transported so far into earth orbit under the general designation "Kosmos" are in no way components of a uniform series. They are of different design and serve quite different purposes. There is uniformity only in that they all work automatically and are as a rule selected for quite definite research missions, such as for the study of the atmosphere, of particle radiation, for geophysical research, or for the perfection of various on-board equipment for kosmonautic objects, or for experiments with them. In spite of these differences, the satellites of the Kosmos series have some common characteristics: Their basic shape is identical. They have the same component groups, a uniform system to control on-board equipment, uniform power supply systems, etc. These components need not all be newly developed every time. They are manufactured in large-scale production, which considerably decreases the cost of space research, and thus, is more economical. In addition, these standardized components make possible a very wide range of variation for the most different missions. They are used for various applications. In the Kosmos satellites, various scientific measuring apparatus and equipment is installed, depending on the group of problems to be studied. To this we can add the extensively standardized components for power supply, radiotelemetry systems with storage systems — designed for radio transmission of scientific measurements to the ground stations — and stabilization systems (if orientation is needed), equipment for radio-control, control systems, programming equipment, and equipment for the heat regulation system. In addition, of course, there is on the Kosmos satellites a radio system for accurate measurement of orbit elements and for transmission of information on the functioning and operating condition of the manifold equipment. In correspondence with the many-sided research program, the Kosmos satellites differ in their power supply. Depending on the mission, chemical power supplies are often used, and solar cells on other occasions.



This Kosmos satellite is equipped with a proton magnetometer to study the intensity of the Earth's magnetic field. The "hat" is the body of the temperature control system.

Some satellites of the Kosmos series return to Earth again after some hours or days, when their flight mission is fulfilled. These are those which would not satisfy their missions by long-distance transmission of results to the earth. They include, for example, satellites on which certain systems or precision instruments are improved or perfected, systems which will then be used later in manned spacecraft. They also include satellites by means of which landing technique is improved, and those which have on-board material for scientific observation, which must be evaluated immediately in laboratories on Earth. Other Kosmos satellites which return to Earth are those in which people have studied the effect of many days of space flight on biological experimental material (plants, animals, insects, and single-celled life). In such cases, the Kosmos satellites are equipped with braking rockets, a special landing container, and a parachute system, in addition to the equipment described previously. The first Kosmos satellite to return to Earth was Kosmos 4, which was launched on 12 April 1962 at an orbital inclination angle of 65 degrees. Since then, dozens of Kosmos satellites, which flew on a 65-degree orbit, have returned to Earth after 8 days or less, such as Kosmos 21, 27, and 47. This category was complemented at the beginning of 1966 by satellites on a new orbit with an orbital inclination angle of 73 degrees to the earth's equator! The active functioning duration of the Kosmos satellites differs, too, among the individual satellites, just as does the total lifetime of that space apparatus which remains in Earth orbit. Thus, for instance, Kosmos 100 will last only about 10 years, while the satellites of the multiple-launch Kosmos 80 to 84, which flew at an initial height of 1,500 km, will remain in their orbits for more than 1,000 years. Every one of the satellites of the eight-fold launch of October 1971 (Kosmos 444 to 451) has a lifetime of 10,000 years!

Up to the present day, the on-board apparatus installed in the Kosmos satellites has proved to be the very best. The scientific measurements collected by the automatic equipment is in its full extent transmitted to the earth on certain frequencies and received by ground stations on the territory of the USSR. It is processed by a central coordinating and computing center and then evaluated in the



This satellite was used to test a stabilization system working with flywheels and electrical drive.

appropriate research institutes of the Academy of Sciences. The Earth-bound control and measuring complex — consisting of dozens of ground stations — also monitors the regular operation of all the on-board apparatus and, with special equipment, measures the current orbital path of the artificial satellites. The coordination and computing center often works with more than 20 Kosmos satellites at once (note, for example, the eight-fold launches), recording the information coming in from them and monitoring the program completion of each one of them. It also occurs that the movements of the cosmic apparatus on its path and the simultaneous axial rotation of the earth makes it impossible to maintain direct radio contact with the Kosmos satellites from USSR territory. In such situations, numerous research ships of the Academy of Sciences, which are stationed in various areas of the seas and oceans, take over the necessary monitoring of the artificial satellites. Usually these are the ships Academician Kurtschatow, Dimitri Mendelejew, Academician Wernadski, Beshiza, Dolinsk, Ristna, Borowitschi, Newel, Morshoewz, Kosmonaut ~~Juri~~ Yuriy Gagarin, Kosmonaut Wladimir Komarow, or the research ship Academician ~~Sergej Koroljow~~ Sergey Korolev. These floating institutes for space communications play no insignificant role in maintaining the /40
experiments in the Kosmos program.

Preparation for Manned Space Flight

In ten years of intensive research using satellites of the Kosmos series, Soviet scientists obtained much new and varied knowledge on space around the earth and the upper layers of the earth's atmosphere. Today, therefore, we have a clear concept of the spectrum and intensity of charged particles out to a distance of 40,000 km from the earth. The magnetic field of the earth was also a steady object of the attention of numerous Kosmos satellites. Artificial satellites, for instance, make possible much faster magnetic mapping of the earth along a much larger section of its surface than would have been possible from ground recordings. This project of magnetic mapping of the earth was carried out by, among others, the satellites Kosmos 26 and Kosmos 49, which were equipped with photon magnetometers. They recorded every change in the intensity of the magnetic field. The data obtained were transferred to special maps. The interaction between the concentration of electron radiation and the structure of the terrestrial magnetic field, which was recorded comprehensively for the first time, is being studied. The global magnetic mapping of the earth covers more than 75% — more than three quarters — of the Earth's surface, and almost simultaneously. On the basis of the results of this research, which are not only of high scientific value, but are also of great practical value, USSR experts were able to demonstrate the existence of three interesting geophysical phenomena, the Brazilian, the North Atlantic, and the Bering anomalies. The data on the magnetic field of the Earth are already finding extensive application in prospecting for mineral resources, in shipping, and in air travel.

A high percentage of Kosmos satellites is intended for study of cosmic radiation and its variations. These include many satellites for the determination of the radiation safety for manned space flight. Thus, for example, by means of the Kosmos 5 satellite, it was possible to get an accurate picture of the results of the USA nuclear weapons test on 9 July 1962. In May 1963, Kosmos 17 obtained enormously important data on radiation in the height range of 600 to 800 km from the earth. It recorded great electron currents which had been generated by the American nuclear explosion, and determined the mean lifetime of these electrons. One reason that this was of great importance was that the Soviet space flight specialists had planned the group flight of the two manned space ships Vostok 5 and Vostok 6 (Valery Bykowski and Valentina Tereschkova) for the following month, June 1963. Thanks to long-term measurements from a whole series of Kosmos satellites, the flight paths of the space ships were studied accurately, and a detailed radiation map was assembled on the radiation conditions at altitudes between 184 and 800 km. With Kosmos 41, charged particles in the magnetosphere of the earth were studied at heights up to 40,000 km. For accurate determination of the lifetimes of artificial Earth satellites and space ships, which is of great importance for the safety of manned space flight, the Kosmos satellites also determined the distribution of atmospheric density in an altitude range between 180 and 320 km. These data were obtained from the aerodynamic braking of the satellites during their flights. The change in density of the high atmosphere depending

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on solar activity was also studied, among other things.

KOSMOS 166 Investigates Solar Radiation

The studies on solar radiation with Kosmos 166 in June, 1967, were of the greatest significance. As is well known, the ultraviolet and X-ray radiation from the sun affect processes in the Earth's ionosphere to a very considerable extent. In times of solar eruptions there is also increased danger of radiation for manned space flights. In previous years, without exception, all flights of Soviet and American astronauts took place extensively in regions with low radiation dose. This was due to the relatively low orbit within the protection of the Earth's magnetic field and low solar activity. But in the second half of 1967 stronger and more frequent solar eruptions began to occur. This was a sign of a new period of increased solar activity, causing enormous danger of radiation in manned space flights. But within just this period, numerous manned space flights by the USA and the USSR were intended to take place (e. g., Sojus 3 to Sojus 8 and Apollo 7 to Apollo 12). For these and other reasons, study of the physical processes occurring in the solar corona and in the adjacent layers of the solar atmosphere were among the most important missions in the search for appropriate solutions to radiation protection in manned space flights. The special solar satellite Kosmos 166 was planned to study the short-wave radiation of the sun. Its design was a modification of the Kosmos series. Due to a highly-developed orientation system, consisting of a gyroscope system and gas jet engines, one axis of the satellite was continuously oriented toward the sun. The scientific apparatus on Kosmos 166 consisted of an X-ray photometer, an ultraviolet diffraction spectrometer, and an X-ray heliograph. The radiation detectors the photometer were Geiger photon counters with an oxygen damping mixture and beryllium or aluminum slits. The studies were done in those spectral regions of particular interest for clarification of the nature of the solar eruptions. The Kosmos 166 satellite carried out its studies for a period of some three months. During this time the sun carried out three full rotations about its axis and, according to reports from observatories on Earth, changed its activity very extensively.

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The experiment with Kosmos 166 made it possible to assemble abundant material on the course of the X-ray eruptions and on their relation to the optically visible eruptions. The coronal origin of the X-ray eruptions provided the assumption that they are closely related to the disturbances in the corona which lead to the corpuscular eruptions which are dangerous for manned space voyages. As soon as we learn to predict the movements of the corpuscular streams correctly, we will be in a real position to predict these "storms" in space. Then space ship occupants can wait out such periods of solar activity on the Earth or evade them by special maneuvers. The measurements from the Kosmos 166 satellite and others were also used to determine the temperature and the electron concentration in the solar corona.

Astronomical and Astrophysical Research

Meteoritic particles in space near earth were not neglected in the Kosmos satellite program. Space ships, automatic space probes, or their construction elements can be damaged on passing through such meteoritic flows. In the course of such experiments, including those with Kosmos 8, it was possible to study the degree of danger from meteorites for manned space flight near the earth at a height range between 250 and 600 km from the Earth. It was established that the density of meteoritic material in space near the Earth is variable. Most of these experiments were done with piezoelectric meteoritic detectors which, to be sure, initially exhibited a deficiency — their inherent noise, which occurs with temperature changes and which can be interpreted as impact of micrometeorites. In some Kosmos satellites, therefore, measures were taken to lower the noise level.

For a long time astronomers and astrophysicists have dreamed of building an observatory outside the Earth's atmosphere, so that they could make observations from there of the universe, uninfluenced by the disturbing effects of the Earth's atmosphere. The stars, and also, of course, the star nearest the Earth, the Sun, radiate great flows of visible light into the universe because of their high

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temperatures. But the stars also transmit invisible rays — the so-called vacuum ultraviolet rays and the soft X-rays, which differ from visible light primarily by their shorter wavelength and also by the fact that this radiation is almost entirely absorbed by the Earth's atmosphere. This radiation, which contains valuable information about the stars and the material of interstellar space, can, then, be studied only outside the air shell of the Earth, in space itself. It should be mentioned that the vacuum ultraviolet radiation and the soft X-radiation from the sun exert a very great effect on the upper layers of the Earth's atmosphere. There they form the so-called layers of the ionosphere which, for example, play an important role in radio communication, including communication with space ships. These radiations, too, were studied by means of the artificial satellites of the Kosmos series, such as Kosmos 262, with which the USSR first undertook a comprehensive experiment to investigate the UV radiation and soft X-radiation outside the Earth's atmosphere:

Kosmos 262 was, basically, an optical observatory for study of solar radiation, of stars, of interstellar material, and for study of the upper layers of the terrestrial atmosphere. The data transmitted to the ground stations from the measuring apparatus made it possible to follow how the radiations became stronger or weaker under the influence of active processes in the outer layers of the Sun.

The Kosmos 261 satellite was also intended for further research on the Sun, the upper atmosphere of the Earth, and the nature of the polar aurora. The main mission of these experiments, which included direct measurements on board the satellite and ground experiments, was the study of geoactive corpuscles, of electrons and protons which generate the aurora, of electrons of ultrathermal energy, and of variations in the density of the upper atmosphere during the time of the polar aurora. These investigations are of great

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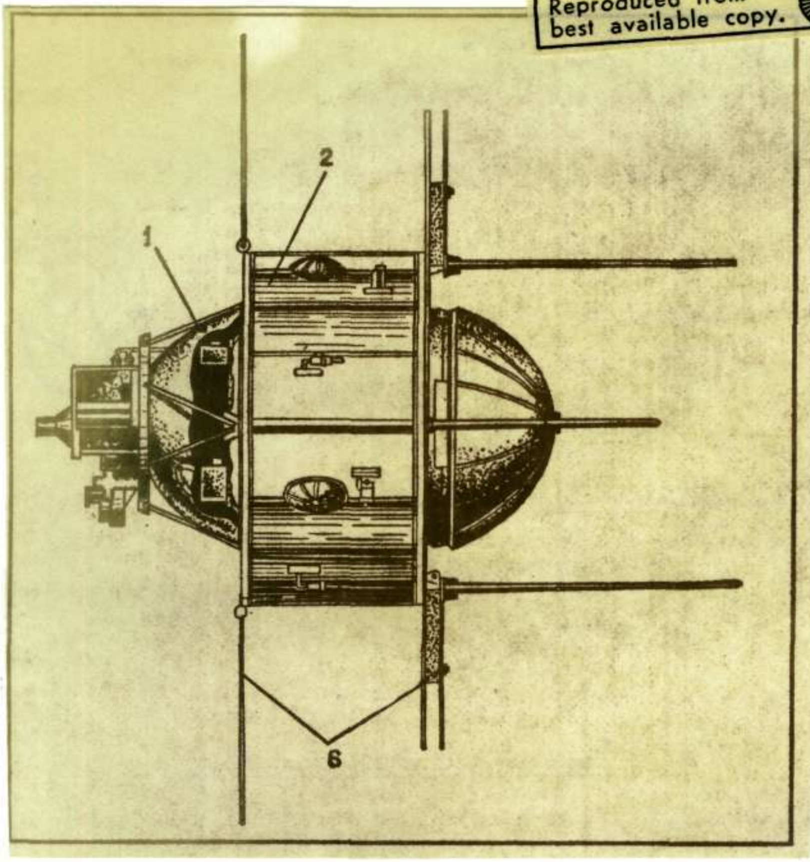
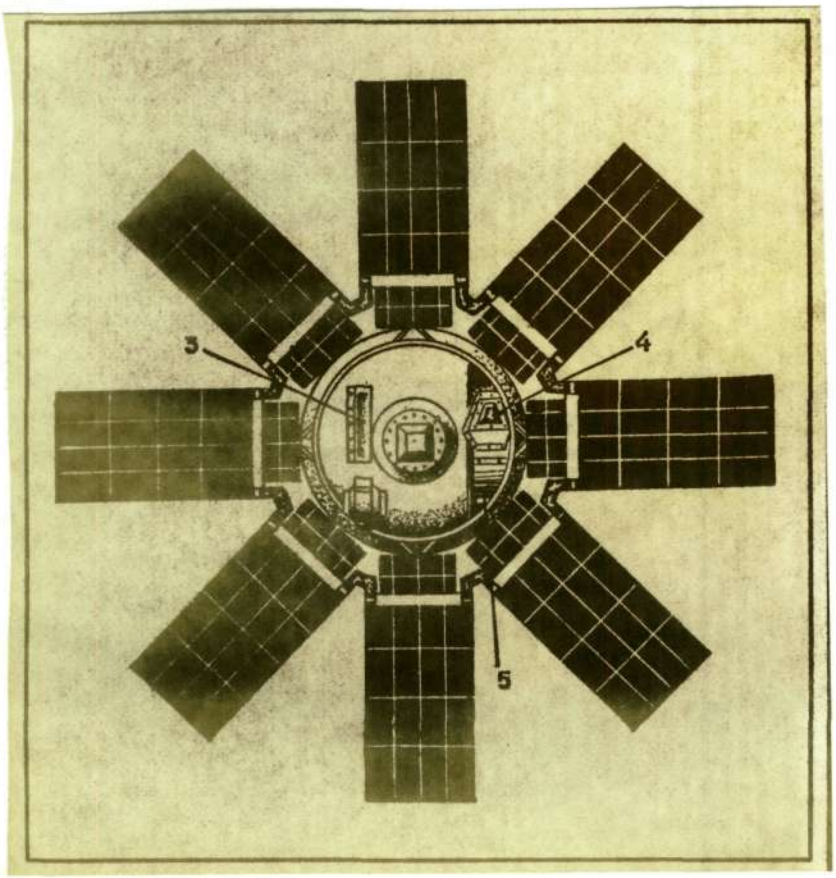
interest for the geophysicists. The Kosmos 261 carried scientific instruments for investigations on the ionosphere, for magnetic measurements, and also optical instruments by means of which the solar radiation was observed in specially selected regions. The main point of the experiment with this artificial satellite was the fact that all these measurements were performed simultaneously, so that the results obtained gave important conclusions about the relation between activities of the Sun and the changes they cause in the upper atmosphere of the Earth. While the program was being carried out on the geocentric orbital path, a so-called chromospheric eruption occurred on the sun. The artificial satellite recorded exactly the beginning and course of this chromospheric eruption. By radioastronomic measurements, Kosmos 261 discovered the so-called photoelectrons in the upper layers of the Earth's atmosphere. These are electrons generated by the UV radiation from the Sun, with an energy range of 60 to 120 electron volts, which occur only with extremely strong ultraviolet radiation. Also, it should be mentioned that Kosmos 261, as a joint satellite of several eastern European countries, also bore the nickname "Friendship Satellite", because the scientific program for this satellite was coordinated by the Council for Interkosmos. It was, therefore, the direct forerunner of Interkosmos 1, which was launched on 14 October 1969. In correspondence with the "Program for Cooperation of the Socialist States in the Area of Research and Utilization of Space for Peaceful Purposes", research institutes and observatories in Bulgaria, Hungary, the German Democratic Republic, Poland, Rumania, the USSR, and the CSSR participated in the Kosmos 261 experiments. The information obtained was also evaluated jointly by the participating countries. /45

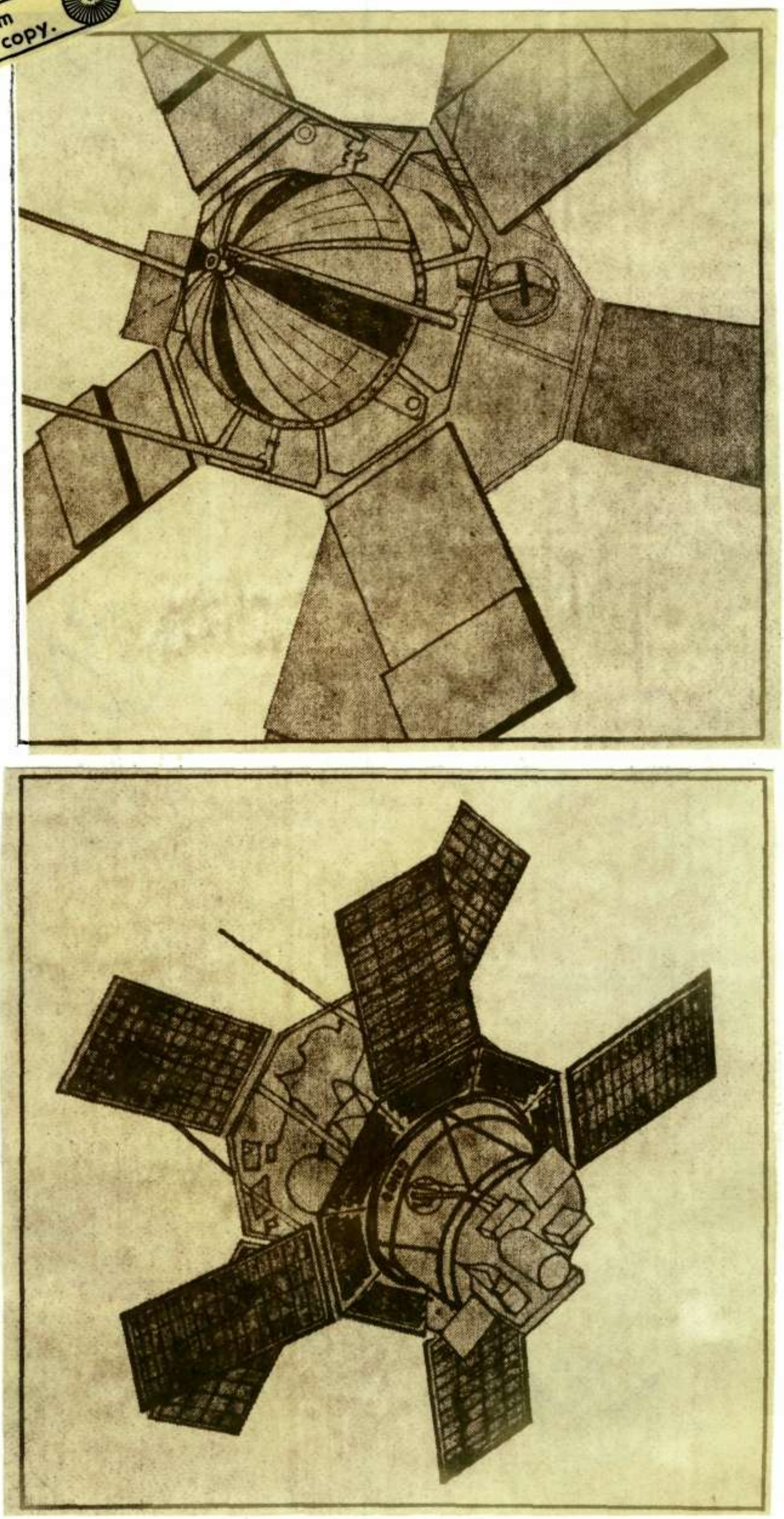
INVESTIGATIONS OF THE EARTH'S ATMOSPHERE

The success of cosmic and rocket technology has shaped anew the character of astronomy — one of the oldest sciences of the Earth. We are witnesses to a sort of "rebirth" of astronomy. By means of the satellites of the Kosmos series, Soviet science for the first time gained the ability to place astronomic telescopes outside the



Kosmos 166, which was launched in June 1967 to study the short wave radiation from the Sun. The two drawings above show the design of the satellite. 1 = the electronic block for the scientific equipment of Kosmos 166; 2 = thermal insulation; 3 = ultraviolet grating spectrometer; 4 = X-ray heliograph; 5 = X-ray photometer. Outside, in a star-shaped arrangement, are the solar cell panels of Kosmos 166. The two lower drawings show: right: an over-all view of the Type 166 satellite for investigation of short-wave solar radiation, and, left: a rear view of the satellite.





Kosmos 166 (see previous page)

envelope of air about the Earth, in order to solve certain problems of extra-atmospheric astronomy and experimental astrophysics. The Kosmos 251 artificial satellite was designed for that purpose, for instance. It was launched in April 1968, and was the first astronomical observatory to carry out observations in space over a long period. There were eight small telescopes on the satellite, with a lens opening (mirror diameter) of 70 mm for the observation of hot stars in various regions. There was also an X-ray telescope which recorded radiations in the spectral range from 0.5 to 5 Ångstrom. Two photometers measured the scattering of solar radiation in the upper layers of the gas envelope about the Earth. Previously, telescopes had been placed outside the Earth's atmosphere only briefly with rockets, or had been carried by balloons into the upper layers of the atmosphere. During the one-month active working period of Kosmos 251, Soviet ground stations were in radio contact with the satellite some 150 times, during which the measurements from the first space observatory were transmitted by radio to the ground stations. The orbital path of Kosmos 251 provided almost ideal conditions for astronomical observations. Only a few problems occured, in relation to the movement of charged particles in the region of the terrestrial radiation belt. In this experiment it was of unusual importance that the satellite was oriented in cosmic space so accurately that satisfactory astronomical observations, and especially photographs, could be made. This purpose was served by a magnetic braking system, which slowed the rate of rotation of the satellite about its own axis by more than a hundred-fold. This operation occurred in separation of the satellite from the last booster stage. The research activity of the first astronomical observatory, Kosmos 251, on its orbit as a satellite of the earth, produced very valuable data on the radiation spectra of the stars and on the hydrogen corona of the Earth, which extends out to distances of several tens of thousands of miles about our planet. In the opinion of astronomers, future telescopes which will be launched into space on the pattern of the earth satellite Kosmos 251 will contribute to unraveling many secrets of the stars. Now, by means of space travel technology, directed astronomical and astrophysical research can be conducted outside the Earth's atmosphere.

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But the gas shell about the Earth itself, its properties, and the extent of the upper layers were objects of numerous studies by satellites of the Kosmos series. Thanks to these automatic laboratories we have significantly changed and expanded our concepts about these problems and about the composition of the atmosphere, about certain characteristics of the Earth's surface, and about its cloud cover. Thus, for example, the density and variation of the upper atmospheric layers were studied in their dependence on the activity of the Sun. Out of the range of these experiments, we can pick Kosmos 149, which was provided with a new type of stabilization system. The scientific equipment on this satellite included two photometers which observed the surface of the earth from opposite directions. The earth radiation proper was measured by a radio probe in the range transmitting infrared radiation with a wavelength of 8 to 12 microns.

The relatively low flight altitude of Kosmos 149 made possible the use of an aerodynamic stabilization system. This ensured orientation on three axes in relation to the flight direction and to the center of the earth, with an accuracy of some 5 degrees. The aerodynamic stabilization system, consisting of a massive cone-shaped ring connected to the satellite by an unusually thin boom several meters long, was deployed immediately after separation of the last stage of the booster rocket, so that it took over the part of a control system. An active braking system, working hydraulically, was used for reduction of the satellite's own oscillations. These generally resulted from the separation from the booster rocket. As only the original perturbing effect itself had to be compensated for, the fuel consumption for this system was very slight.

An interesting situation appeared in all investigations of the upper layers of the atmosphere by the Kosmos satellites: The upper layer of the atmosphere, warmed by the short-wave solar radiation, "breathed" to a certain extent. That is, its height above the Earth's surface increased and then decreased again. Accurate knowledge about the mechanism of this phenomenon is very important, for example, to those scientists who calculate orbits for satellites, make rendezvous and docking maneuvers safe on the orbital path, and solve problems of the return of space vehicles on their entry into the Earth's atmosphere at twice the escape velocity.

Other satellites of the Kosmos series also recorded the ozone absorption bands of the Earth by means of ultraviolet spectrometers. In this way the vertical displacement of the air masses in the atmosphere can be studied. The brightness of the Earth's surface was also measured with photometers, not only on the side of our planned illuminated by the Sun, but also on the "dark" side.

METEOROLOGIC STATIONS IN THE COSMOS

In the ten years since the satellites of the Kosmos type were started, we have become accustomed to the regular dispatch of these automatic research satellites into space, and we tend to regard them as marginal incidents to the other "great" experiments in astronautics. In this we forget somewhat that these artificial Earth satellites of the Kosmos type furnish unusually valuable information in many areas, which is of great direct importance for happenings on the Earth. In this relation, let us mention specifically those Kosmos satellites which make up the "Meteor" meteorological system, because one of the most important problems faced by mankind is the provision of a world-wide weather service. As is well known, the errors in weather prediction are linked to the insufficient knowledge of the state of the atmosphere. To be sure, thousands of ground stations (weather stations) are scattered over the surfaces of the continents, but the oceans and certain areas which are particularly poorly accessible (poles, etc.) are still empty spaces for the meteorologists. Yet is is over just such areas that hurricanes, cyclones, and anticyclones originate and develop. For accurate prognosis of the weather phenomena, then, it is unavoidably necessary to know what is occurring in the air layers of the atmosphere in just these areas. The USSR began to develop a global weather system in 1963. It includes several Kosmos satellites and their ground stations.

In the first stage, the electronic devices were tested in the space electrical power laboratories Kosmos 23, 45, 65, and 92. The last satellite also tested infrared pictures. In the second stage, there followed the satellites of the type of Kosmos 122. It carried electro-optical equipment and a system which ensured the operation of the satellite on its orbit for many months. The third state of development of a meteorological observation system was concluded with the launch of the satellites Kosmos 144, 156, 184, 206 and 226. These weather satellites had television transmitters for day and night operation, infrared equipment for measurement of the temperature of the surface, and actinometric apparatus which measured the reflected and emitted radiation. These experimental weather observation satellites became part of an application series, and their successors after 1969 received the designation "Meteor". The weather information was supplemented by large-area cloud pictures, which the television satellite Molniya 1 provides from several tens of thousands of kilometers distance from the Earth. In the collection of meteorological data, as for the astronomical studies mentioned previously, exact orientation of the artificial satellite is space is necessary. /46
The meteorological Earth satellite must be oriented accurately in order to perform accurate observations and to transmit the stored data to Earth as it flies over the home ground stations. This orientation is done by means of electrical motors.

The first meteorological satellite of the Soviet Union was Kosmos 122, which was launched on 24 June 1966. During its two months of operation on its orbit it was of great service in increasing the precision of weather forecasts. It communicated the state of the Earth's atmosphere to Earth in television pictures in which the clouds and there movements could be seen clearly. Thanks to these television transmissions, cloud cover maps could be made up at the receiving centers. On the night, shadow side of the planet, Kosmos 122 made photographs at a wavelength of 8 to 12 microns. The intensity of the radiation from Earth into space was measured at the same time. The observations collected by Kosmos 122 were also sent to the hydrometeorological Center of the USSR, where they were processed by a Universal computer, edited, and prepared for further evaluation. This machine processed more than 200 telemetric

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observations simultaneously. This is necessary, if one considers that a weather satellite, during one orbit, collects more separate pieces of information than ten thousand ground stations together! After the Soviet scientists and technicians had measured with Kosmos 122 how long such an artificial heavenly body could follow its path about the earth, it was possible to launch the twin pair, Kosmos 144 and Kosmos 156, which moved on a nearly polar orbit with an orbital inclination angle of 81.2 degrees. They were the world's first long-life space meteorological stations with complete scientific and technological equipment. They furnished meteorological information over 60% of the surface of the Earth (in the course of some days). On each revolution they furnished information on the cloud cover for some 8%, and on the amount of heat radiated out for some 20% of the Earth's surface. It was also extremely important for analysis and prediction of the weather that after exactly six hours one satellite checked the same area that its "partner satellite" had observed previously.

Today there are dozens of satellites in the Meteor system. They have been able to discover hundreds of cyclones and specify the locations of thousands of weather fronts. All these observations were transmitted operationally to the marine and air weather services of many countries. Following are some concrete examples which explain the usefulness and effectiveness of the service from the extra-terrestrial meteorological satellite. By means of television pictures which Kosmos 184 provided from the Antarctic, the existence of great vortices formed on ice fields was discovered. At first, the workers in the hydrometeorologic Center of the USSR had considered these vortices, which have diameters of about 200 meters, and which lie over the Antarctic continent, to be the well-known cloud fields of cyclones. But closer study of these phenomena showed that we were dealing not with atmospheric, but with oceanic patterns. Theoretical studies by oceanologists showed that a closed circulation of the shore waters must be present at the Antarctic shores. But even more: After study of the pictures from Kosmos 184 we can say that some medium-sized atmospheric vortices, the so-called meso-vortices, are directly related to such closed circulations in the oceans. The ice vortices were in the meantime observed by American specialists

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with their weather satellites. With the help of several Kosmos weather satellites of the Meteor system it was possible for the first time in December, 1968 — the summer season for the Southern hemisphere — to produce a complete map of the Antarctic coast and the ice formations about that continent. Kosmos 226 provided important services in reconnoitering the ice. It furnished daily pictures of those regions covered by the research ships of the 14th Soviet Antarctic expedition. Or another example: A giant floating dock was en route from the Black Sea to the Far East when a powerful cyclone was found to have originated over the Indian Ocean, exactly on the course of the dock. On the basis of data from the meteorological Kosmos satellites, the tugs changed the course of the dock and the cyclone passed by without damage. Also, the meteorological satellites warned of the origin and movement of the hurricanes Alice, Cora, Nora, Gilda, Emma, Georgett, Henriette, and others, so that inhabitants of the coastal areas or countries affected could get to a place of safety from the destructive power of these dangerous cyclones in good time. In this way the main weapon of elemental catastrophes, suddenness, was circumvented.

The Kosmos weather satellites of the Meteor system give information about the distribution of the cloud cover, on the boundaries and structure of snow and ice fields, on the centers of origin of cyclones, anticyclones and typhoons, and on the direction of their movement. Through their help, meteorology has become global, more accurate, and more effective. For some time the data obtained and the collected results of weather forecasts have been exchanged regularly between the central weather services of various countries. In this way, a world-wide weather service is slowly developing.

AN ORBITING BIOLOGICAL LABORATORY

Soviet space scientists have also performed medical-biological studies using individual devices of the Kosmos series. For instance, the special satellite Kosmos 110 served for such studies. It circled the earth for 22 days with the two dogs, Veterok and Ugolyok, as well as scientific equipment. Then, on March 16, 1966, on its

330-th orbit, it was landed again on the Earth, in good condition and on the intended area. This experiment took place at a time when the Soviet Kosmonauts had not yet been maintained for more than five days in the weightless condition of space. Therefore, Kosmos 110 was primarily concerned with the following two questions for future operations:

- Is it possible for Man to adapt to the state of long-term weightlessness?
- If such adaptation occurs, then how dangerous or problematical will it be for the people to return to the gravitational field of the Earth?

Kosmos 110 contained two cabins, in which the dogs "Veterok" (the main experimental animal) and "Ugolyok" (the control animal) were placed, and in which they could assume different positions. The dogs wore corset costumes, by means of which they were fastened to the cabins. These carried pulse generators and communication connections for research purposes and for provision of nutrient. (Food and water were provided through a stomach fistula.) Still other experimental biological objects were placed on Kosmos 110 in special containers: various strains of yeast, blood sera, protein preparations, some strains of Chlorella and lysogenic bacteria.

During the three-week space flight of Kosmos 110 the average blood pressure, the respiration and pulse rate, as well as electrocardiograms, seismocardiograms, and sphygmograms were recorded by means of biomedical signal transducers (including implanted electrodes) on both experimental animals. With the aid of television cameras, and by noting physiologic characteristics, the conditions of the experimental animals and the functioning of the life support system were observed continuously. Both dogs were under continuous observation. The orbit chosen for Kosmos 110 (perigee 187 km, apogee 904 km) allowed the satellite to penetrate periodically into the lower radiation belt of the Earth. In this way, it was possible to investigate and test practically the protective shielding to be used later in the manned Soyuz space ships. Among the many studies, the detailed study of the heart activity and the activity of the entire circulatory system in particular gained special importance. The condition of the dogs Veterok and Ugolyok was satisfactory through all the 22 days of space flight. After the flight, too, the findings were good, although they naturally gave somewhat an impression of fatigue.

In the following investigations, the Soviet scientists detected rather great changes in the locomotive apparatus of the animals. The muscle mass of the animals had decreased, the gait had changed, and the usual movements were performed uncertainly. But eight to ten days after return to Earth the movements had completely normalized. On the first day after the space flight an increased calcium content was found in the blood and urine of Veterok and Ugolyok. The fact that calcium was "washed out" of the organism was confirmed by X-ray study of the bones. The animals lost weight during the space flight, although the investigations of the functions and structure of the liver and other organs showed that both dogs had eaten enough food in space. Apparently this weight loss is due primarily to the decrease in muscle mass and to certain water losses. The dogs showed an increased pulse rate after the flight. Complete recovery of the activity of the circulatory system appeared on the fourth to fifth day after return to Earth. The blood showed changes on the third, fourth, and particularly on the fifth day. There was a significant acceleration of the sedimentation rate and an increase in the number of white corpuscles. The results of microbiological and immunobiological studies confirmed these findings to a certain extent. To be sure, the scientists are of the opinion that the data obtained with such animal experiments can be applied to humans only with extreme precautions, but there are some general regularities. The 18-day flight of the Soyuz 9 crew in /47 June, 1970, showed this also. Like the Kosmos 110 experiment, it showed that the conversion of the living organism from the state of weightlessness to Earth gravitation is significantly more difficult than the adaptation in the opposite direction. For example, the Kosmonauts Nikolayev and Sevastiyanov required fully ten days after returning from their 425 hour stay in space to regain their normal capabilities. In spite of regular, intensive training with exposure to severe stresses, certain muscle groups in the Soyuz 9 Kosmonauts weakened considerably because of the state of long-lasting

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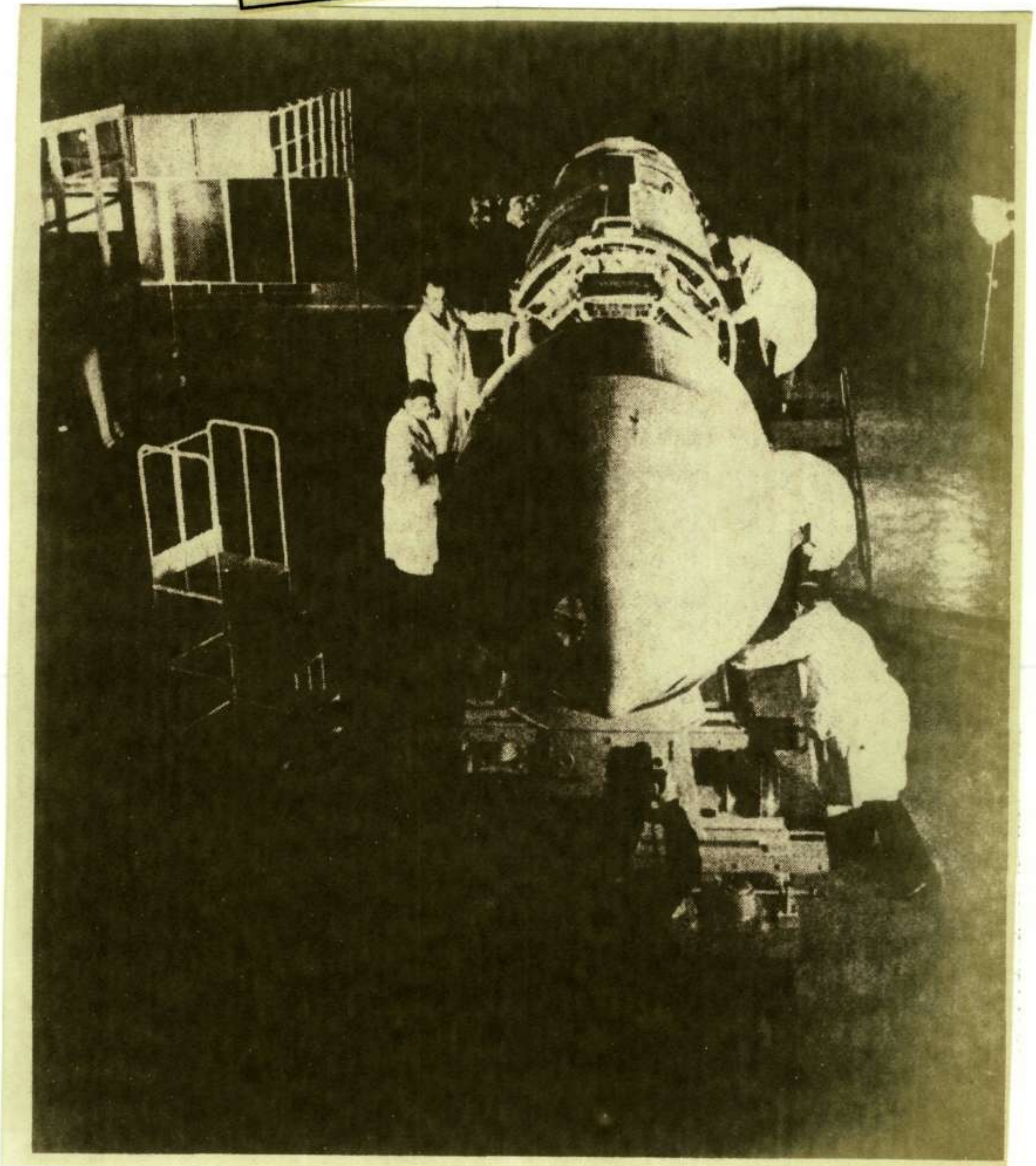
weightlessness. This was particularly true for the arm and leg muscles. The space fliers could raise their arms only with effort, and various objects seemed unusually heavy to them. Normal, upright motion offered the greatest difficulties for them. They could move forward only with legs spread and with sliding steps. Outwash of calcium from the bones was also established. From these cautions parallels we can see that the Kosmos 110 experiment quite considerably expanded knowledge about the effect of cosmic radiation and long-term weightlessness on the functions of the living organism.

AUTOMATIC DOCKING IN SPACE

The historic flight of the two artificial satellites, Kosmos 186 and Kosmos 188, in November 1967 takes a particularly important place among the problems of space flight technology solved within the framework of the USSR Kosmos satellite program. For the first time, /48
they carried out an automatic rendezvous and docking maneuver in orbit about the earth. This laid the cornerstone for the production space stations and the assembly of large interplanetary space ships in earth orbit. These missions are among the next major steps in space travel. Space stations will be manned for a longer period and will carry out different types of scientific, technological, and economic missions. But, as these A-stations will reach large dimensions and, therefore, high mass, it is impossible to launch them into space in the assembled state. This would require booster rockets with unbelievable dead weight. Therefore, the final assembly of future space stations from various components must be accomplished in orbit, either fully automatically or manually, i. e., with the active participation of cosmonauts occupying spacecraft. The method depends on what problems must be solved in the docking. Kosmos 186 and Kosmos 188 showed the first route to be applied for automatic docking of two earth satellites in space. Kosmos 186 served as the active satellite. During its first three days of flight the on-board systems, engines, and orientation systems were tested and the flight path was corrected. Then Kosmos 188, the passive part of the experiment, was launched.



Kosmos 261 Earth satellite with the last stage of the two-stage Kosmos booster rocket in the assembly building in preparation for launch.

The original distance between the two satellites in orbit was some 25 km. Kosmos 186 and 188 took bearings on each other with their radio-location methods, and measured the parameter of relative motion. On the basis of these data, the electronic on-board control systems worked to orient the two satellites to each other, and the orientation and control systems carried out the necessary maneuvers automatically. When the distance between Kosmos 186 and 188 was a few hundred meters, the further planned approach took place with special small control jets. The docking maneuver took place over the Pacific Ocean, and the two linked satellites made two revolutions about the earth together in 3 hours and 50 minutes. Then the two were separated on a radio command from the ground station, and the flight continued on separate orbits. After carrying out the flight program, Kosmos 186 and Kosmos 188 returned to the ground again in good condition. A similar test was repeated in April 1968, with the two satellites Kosmos 212 and 213. This prepared the way for the erection of the world's first experimental space station, which was constructed in low Earth orbit in January, 1969 from the two manned spacecraft Soyuz 4 and Soyuz 5.

Kosmos 213 was also characterized by the fact that, like its forerunner Kosmos 140, it carried equipment for testing superconducting magnet coils. These two Kosmos experiments with superconducting electromagnets confirmed the view that it is possible to maintain temperatures near absolute zero in space flights. In the future, then, superconducting systems with which uncommonly strong magnetic fields can be generated, may be installed in space equipment. The complex system on Kosmos 213, which consisted of two coaxially layered superconducting coil systems, generated a magnetic field with the considerable strength of nearly two million amperes per meter. With such a powerful field, for example, even the primary cosmic radiation can be analyzed. These experiments with Kosmos 140 and Kosmos 213 offer a great prospect for space travel because, for example, the Kosmonaut occupants of a space craft having a strong magnetic field built about it can reliably be protected from radiation. Or a superconducting coil in which an electric current circulates can serve for energy storage on a space ship, just as it is practical to base orientation and control systems on the gyroscope principle. Powerful magnetic fields can also be used for magneto-hydrodynamic braking of spacecraft on reentry into the Earth's atmosphere. Finally, very small memory systems for enormous amounts of information, the so-called cryotrons, can be made with superconducting equipment.

SUMMATION

To conclude this report on the Soviet Kosmos satellite program, let me quote from a report by Yuri A. Gagarin (1934-1968), who was the first man to fly in space: "Today hundreds of complex and clever robots follow their paths about our planet. They help us to make further studies of the structure of the earth; to predict the weather; to establish routes for ships; to establish wireless communications between the most distant parts of the earth, and many other things. But with all the importance of the automatic earth satellites, the decisive word is with humanity. We would be happy if some day we could walk on the surface of another heavenly body. But what we want most is the well-being of people here on our earth with the aid of the successes and information from space travel!"

The great manned space stations will bring us decisively nearer this goal. They will be the continuing space laboratories of the future. They will combine in themselves the missions which today are distributed among many hundreds of different measurement and research satellites, and in this way will bring great economy to space travel. A-stations will bring great good for humanity — but before they can be assembled in series in Earth orbit, much must be investigated, studied, researched, explained, produced, and perfected. And here the Kosmos satellites offer valuable help.

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